P4.55A SATELLITE REMOTE SENSING OF TEMPERATURE AND PRESSURE BY THE STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III

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1. INTRODUCTION

SAGE III is the fifth generation of solar occultation instruments designed by NASA to measure vertical profiles of aerosols and gaseous species in the atmosphere (McCormick *et al.*, 1991). Unlike its predecessors, SAGE III makes multi-spectral measurements of the oxygen A band that can be used to infer profiles of temperature and pressure. The profiles will extend from the surface (or cloud top) up to 85 km and their vertical resolution will be approximately one kilometer.

As part of NASA's Mission to Planet Earth (MTPE), Earth Observing System (EOS) program, SAGE III instruments are currently scheduled to fly onboard the polar-orbiting Meteor-3M satellite (mid-1999), the International Space Station (2002), and a future flight of opportunity. SAGE III will use the solar occultation technique to measure the attenuation of the Sun's rays as they pass through the limb of the Earth's atmosphere during each satellite sunrise and sunset. This method is well suited for long-term monitoring of the atmosphere since the instrument is re-calibrated during each sunrise and sunset event. Given this inherent insensitivity to long-term instrument degradation and the expected lifetime of the instruments (6+years), the SAGE III suite of instruments should provide a continually-calibrated, high vertical resolution temperature and pressure data set that will be valuable for long-term monitoring of the stratosphere and mesosphere.

2. O_2 A-BAND CHARACTERISTICS

The oxygen A band, centered near 760 nm, is one of four absorption bands of molecular oxygen in the visible and near-infrared region of the spectrum. The A band possesses numerous features that make it particularly useful for remote sensing of temperature and pressure. Of key importance is the fact that molecular absorption by the oxygen A-band is strongly dependent on atmospheric temperature and pressure. Another important feature is that the A band resides in a relatively "clean" portion of the atmospheric spectrum, and hence radiative transfer in this region is dominated by molecular oxygen absorption with only small contributions from aerosol extinction, ozone absorption, and molecular scattering. Since the line intensities near the center of the A band are quite strong, high signal-to-noise measurements can be obtained. In addition, the temperature dependence of the line intensities varies from positive to negative over the band. For example, at wavelengths far from the band center, the line strength decreases with increasing temperature, while at wavelengths close to the band center, the line strength increases with increasing temperature. All of these unique features can be utilized for accurate temperature and pressure sensing.

SAGE III will make measurements of the oxygen A-band absorption spectrum using 14 channels equally spaced at approximately 1-nm intervals from 759 to 771 nm. The spectral resolution of each channel is about 1.4 nm. Figure 1 illustrates the fine line structure present in the oxygen A-band absorption spectrum and the spectral resolution attainable with SAGE III.

3. RETRIEVALS

A global fit approach (Carlotti, 1988), that uses a non-linear least squares procedure to simultaneously fit measured absorptivities from all spectral channels and slant paths, has been adopted to perform the SAGE III temperature and pressure retrievals. The algorithm is an iterative procedure that attempts to minimize the

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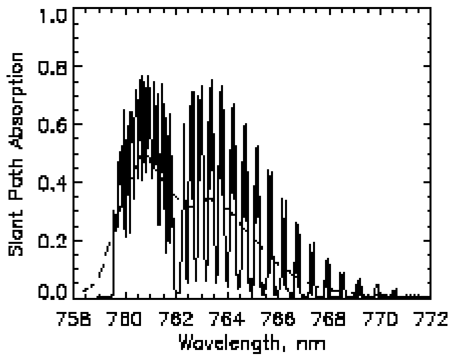

Figure 1. Oxygen A-band slant path absorption spectrum for a tangent altitude of 20km. The solid line represents a spectral resolution of ~0.06nm and the dashed line represents the SAGE III resolution of ~1.4nm.

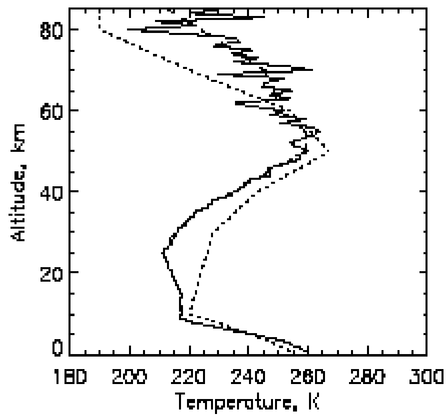

Figure 2. Simulated SAGE III temperature retrieval. The dotted line is the first-guess profile, the dashed line is the modeled profile, and the solid line is the retrieved profile. profile by the dotted line, and the retrieved profile by the solid line

differences between the measured and modeled A-band absorptivities by adjusting a "working" temperature and pressure profile until convergence is reached. A more detailed discussion of the algorithm can be found in Pitts *et al.* (1997).

An example of a simulated temperature retrieval is shown in Figure 2. The retrieval was performed using simulated SAGE III oxygen slant path absorption measurements that included a realistic component of random noise based on the expected signal-to-noise ratio. In this example, the modeled temperature profile is represented by the dashed line, the first-guess profile by the dotted line, and the retrieved profile by the solid line. The retrieved temperature profile reproduces the modeled atmosphere extremely well in the troposphere and lower stratosphere, but exhibits some oscillations above 50 km. The actual differences between the retrieved and modeled temperatures and pressures in this example are shown in Figure 3. The oscillations above 50 km are apparent in both the retrieved temperature and pressure profiles.

Several methods to constrain the retrieval have been tested in effort to reduce the amplitude of these oscillations. Presently, the most satisfactory results have been obtained using a constraint that requires the temperature and pressure adjustments to be in approximate hydrostatic balance. Implementation of this hydrostatic constraint reduces the amplitude of the oscillations significantly as shown in Figure 4. The differences between the retrieved and modeled pressures were dramatically reduced. Clearly, the quality of the retrieved products can be improved with an appropriate constraint and although the hydrostatic constraint appears very promising, the exact implementation of the constraint is an ongoing research topic.

Operationally, the first-guess temperature and pressure profiles will be derived from National Centers for Environmental Prediction (NCEP) data obtained within 12 hours of the SAGE III measurements. The NCEP data will be supplemented at high altitudes with climatological data. A sensitivity study was conducted to quantify how the accuracy of the first-guess temperature and pressure profiles affected the retrieved products. In this study, an isothermal, exponentially-declining atmosphere was used as an extreme case of a bad first-guess. Results indicate that the algorithm is robust and virtually unaffected by inaccurate first-guess profiles.

4. EXPECTED UNCERTAINTIES

In order determine the accuracy of the SAGE III temperature and pressure products, an understanding of the various experimental uncertainties and their effect on the retrieval products is required. These uncertainties include both random and systematic components.

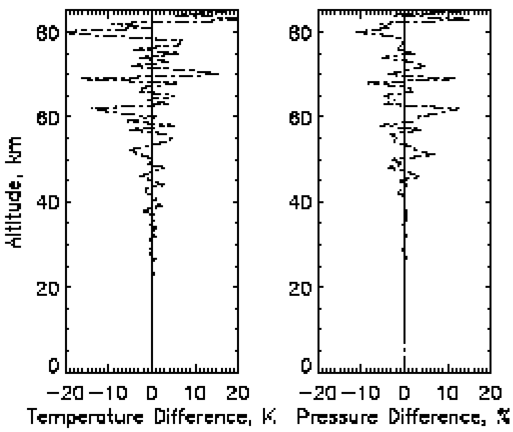

Figure 3. Differences between modeled and retrieved temperature and pressure profiles.

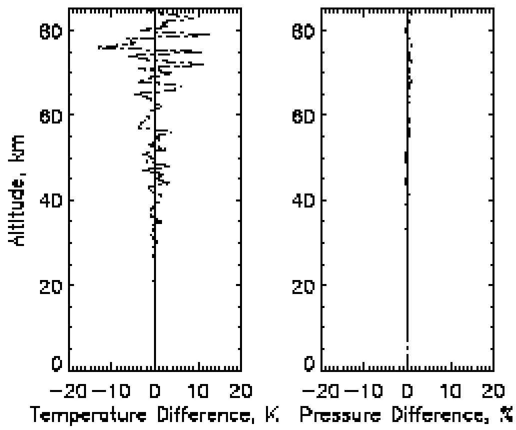

Figure 4. Differences between modeled and retrieved temperature and pressure profiles for a constrained retrieval.

4.1 Random

The dominant component of random uncertainty in the retrieved temperature and pressure products is associated with the random noise in the SAGE III measurements themselves. However, there are also uncertainties in clearing the interfering species (aerosol, ozone, and molecular scattering) from the measurements which will propagate into temperature and pressure uncertainties. The simulated retrievals discussed in the previous section included only the random measurement noise component of uncertainty, so the differences shown in Figure 4 are indicative of the uncertainties in temperature and pressure due to just the random measurement noise. In order to quantify the total random component of uncertainty, the magnitudes of the uncertainty in clearing the interfering species from the SAGE III measurements must be estimated.

The uncertainty in clearing the aerosol component from the A-band measurements is expected to be on the order of 1% of the aerosol slant path optical depths. Similarly, the uncertainty in clearing the ozone component from the A-band measurements is expected to be on the order of 0.5% of the ozone slant path optical depths. Operationally, the aerosol and ozone slant path optical depths in the oxygen A-band channels will be estimated from simultaneous measurements at wavelengths outside the A-band spectral region.

The molecular scattering component of transmission is only dependent on atmospheric density (i.e. temperature and pressure), and therefore leaving this component in the A-band measurements may not be detrimental to the accuracy of the retrievals. Indeed, sensitivity studies indicate that not removing the molecular scattering component has no negative impact on the retrieved products, and in fact, may improve the quality of the retrievals above 50 km. Current plans are to not clear the molecular scattering component from the measurements.

In Figure 5 are shown the individual components of uncertainty in temperature and pressure due to measurement noise (solid line) and uncertainties in clearing aerosol (dotted line) and ozone (dashed line). Clearly, the largest uncertainties in temperature and pressure will be from measurement noise, especially above 40 km. Below 40 km, uncertainties in clearing aerosol and ozone result in temperature uncertainties of less than 1 K and pressure uncertainties of less than 0.5 %.

4.2 Systematic

In addition to the random uncertainties discussed above, there will be systematic uncertainties of which the dominant component will be due to uncertainties in the oxygen A-band spectroscopy. The primary molecular line parameters required for the SAGE III temperature and pressure retrievals are the oxygen line intensities and the line widths associated with air broadening. There currently exists a wide discrepancy in the available oxygen line parameter data. For example, the

1996 HITRAN database adopted the Ritter and Wilkerson (1986) measurements of the oxygen A band line intensities which, although very precise, differ significantly from other studies. In general, existing oxygen line parameter databases have a range of about 15% in line intensities and 30% in line widths.

Sensitivity studies were performed to estimate the effect of possible biases in the oxygen spectroscopy on the SAGE III retrieved temperature and pressures. These studies indicate that a 15% bias in the line intensities will result in about a 1-2 K error in the retrieved temperatures and a 10-15% error in the retrieved pressures. A 15% bias in line widths will result in about a 1-2 K error in temperature and a 7% error in pressure, but these effects are primarily below 20 km.

Due to the relative sensitivity of the SAGE III temperature and pressure retrievals to uncertainties in the oxygen line parameter data, NASA has funded a research effort to produce a new, validated database of oxygen line parameters for use in the SAGE III algorithm. This new database should be available before launch of the first SAGE III instrument.

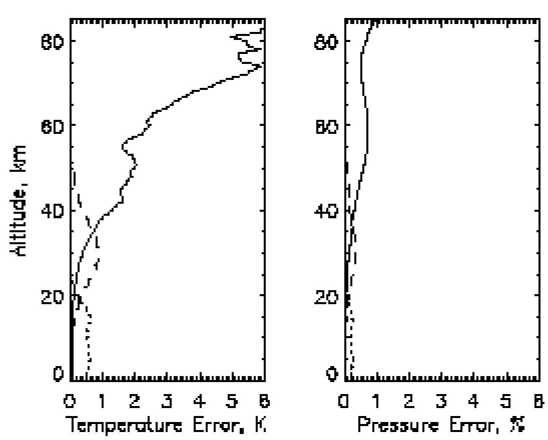

Figure 5. Expected random uncertainty in retrieved temperature and pressure profiles due to aerosol (dotted line), ozone (dashed line), and measurement noise (solid line).

5. SUMMARY

The new SAGE III instruments have the capability to retrieve high quality profiles of temperature and pressure over a broad range of the atmosphere from the troposphere well into the mesosphere. Simulated retrievals have been used to demonstrate the feasibility of the approach. Sensitivity studies to estimate the accuracy of the retrieved temperature and pressure products indicate the random component of temperature uncertainty is less than 1-2 K below 50 km and less than 6 K between 50 – 85 km. The random component of pressure uncertainty is less than 2%. The accuracy of the operational products will of course also depend on the systematic uncertainties in the spectroscopy.

REFERENCES

Carlotti, M., 1988: Global-fit approach to the analysis of limb-scanning atmospheric measurements, *Appl. Opt.*, **27**, 3250-3254.

McCormick, M. P., W. P. Chu, J. M. Zawodny, L. E. Mauldin, and L. R. McMaster, 1991: Stratospheric Aerosol and Gas Experiment III (SAGE III) aerosol and trace gas measurements for Earth Observing System (EOS), *SPIE* Paper No. 1491-16.

Pitts, M. C., W. P. Chu, and L. W. Thomason, 1997: Remote sensing of temperature by the Stratospheric Aerosol and Gas Experiment III, *IRS '96: Current Problems in Atmospheric Radiation*, W. L. Smith and K. Stamnes (Eds.), A. Deepak Publishing, Hampton, Virginia, 586-589.

Ritter, K. J. and T. D. Wilkerson, 1987: High resolution spectroscopy of the oxygen A band, *J. Molec. Spectrosc.*, **121**, 1-19.